Equilibrium Questions

Consider the following chemical reaction:

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2HI\,(g)$$

At equilibrium in a particular experiment, the concentrations of H_2, I_2, and HI were 0.15 M, 0.033 M, and 0.55 M, respectively.

i) Write the expression for the equilibrium constant.
ii) What is value of the equilibrium constant?

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.55M)^2}{(0.15M)(0.033M)} = 61$$

The value of K_{eq} for the equilibrium

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2\,HI\,(g)$$

is 794 at 25 °C. What is the value of K_{eq} for the equilibrium below?

$$\tfrac{1}{2}H_2\,(g) + \tfrac{1}{2}\,I_2\,(g) \rightleftharpoons HI\,(g)$$

$$K_c' = \frac{[HI]}{[H_2]^{\frac{1}{2}}[I_2]^{\frac{1}{2}}} = \sqrt{K} = 28.2$$

A reaction vessel is charged with hydrogen iodide, which partially decomposes to molecular hydrogen and iodine:

$$2HI\,(g) \rightleftharpoons H_2(g) + I_2(g)$$

When the system comes to equilibrium at 425 °C, $P_{HI} = 0.708$ atm, and $P_{H2} = P_{I2} = 0.0960$ atm.. What is the value of K_p?

$$K_p = \frac{[H_2][I_2]}{[HI]^2} = \frac{(0.0960\,atm)^2}{(0.708\,atm)^2} = 0.0184$$

Acetic acid is a weak acid that dissociates into the acetate ion and a proton in aqueous solution:

$$HC_2H_3O_2\,(aq) \rightleftharpoons C_2H_3O_2^-\,(aq) + H^+\,(aq)$$

At equilibrium at 25 °C a 0.100 M solution of acetic acid has the following concentrations: $[HC_2H_3O_2] = 0.0990$ M, $[C_2H_3O_2^-] = 1.33 \times 10^{-3}$ M and $[H^+] = 1.33 \times 10^{-3}$ M. The equilibrium constant, K_{eq}, for the ionization of acetic acid at 25 °C is ___________.

$$K_{eq} = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} = \frac{(1.33\times10^{-3}\,M)^2}{(0.0990\,M)} = 1.79\times10^{-5}$$

Dinitrogen tetraoxide partially decomposes according to the following equilibrium:

$$N_2O_4\,(g) \rightleftharpoons 2NO_2\,(g)$$

A 1.00-L flask is charged with 0.400 mol of N_2O_4. At equilibrium at 373 K, 0.0055 mol of N_2O_4 remains. What is the K_{eq} for this reaction?

$N_2O_4 \rightleftharpoons 2NO_2$

I 0.400M   0

* C -0.3945   +0.789M

E 0.0055M   0.789M

$$K_{eq} = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(0.789M)^2}{0.0055M} = \boxed{113}$$

At 22 °C, $K_p = 0.070$ for the equilibrium:

$$NH_4HS\,(s) \rightleftharpoons NH_3\,(g) + H_2S\,(g)$$

A sample of solid NH_4HS is placed in a closed vessel and allowed to equilibrate. Calculate the equilibrium partial pressure (atm) of ammonia, assuming that some solid NH_4HS remains.

$$K_p = [NH_3][H_2S] = 0.070$$

$$x^2 = 0.070$$

$$x = \boxed{0.26\text{atm} = P_{NH_3}}$$

The equilibrium constant (K_p) for the interconversion of PCl_5 and PCl_3 is 0.0121:

$$PCl_5\,(g) \rightleftharpoons PCl_3\,(g) + Cl_2\,(g)$$

A vessel is charged with PCl_5, giving an initial pressure of 0.123 atm. At equilibrium, the partial pressure of PCl_3 is __________ atm.

$\frac{-b \pm \sqrt{b^2-4ac}}{2a}$

$PCl_5 \rightleftharpoons PCl_3 + Cl_2$

I 0.123 atm   0   0

C -x   +x   +x

* E 0.123-x   x   x

$$K_p = \frac{[PCl_3][Cl_2]}{[PCl_5]} = 0.0121$$

$$\frac{x^2}{0.123-x} = 0.0121$$

$$x^2 + 0.0121x - 0.00149 = 0$$

$$x = 0.0330\text{atm} = [PCl_3]$$

For the reaction below, $K_p = 0.0198$ at 721 K.

$$2HI\,(g) \rightleftharpoons H_2\,(g) + I_2\,(g)$$

In a particular experiment, the partial pressures of H_2 and I_2 at equilibrium are 0.710 and 0.888 atm, respectively. The partial pressure of HI is __________ atm.

$$K_p = \frac{[HI][I_2]}{[HI]^2} = 0.0198$$

$$\frac{(0.710\text{atm})(0.888\text{atm})}{x^2} = 0.0198$$

$$31.8 = x^2$$

$$\boxed{5.6\text{atm} = x}$$

More Complex Equilibrium Problems

A 1.00 L flask is filled with 1.000 mol of H_2 and 2.000 mol of I_2 at 448°C. The value of the equilibrium constant K_c for the reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K_c = \frac{[HI]^2}{[H_2][I_2]} = 50.5$$

at 448°C is 50.5. What are the equilibrium concentrations of H_2, I_2, and HI in moles per liter.

	H_2	$+ I_2$	$2HI$
I	1.00 mol	2.00 mol	0
C	$-x$	$-x$	$2x$
E	1.00 M $-x$	2.00 M $-x$	$2x$
	$\boxed{0.065M}$	$\boxed{1.065M}$	$\boxed{1.87M}$

$$\frac{(2x)^2}{(1.00-x)(2.00-x)} = 50.5$$

$$4x^2 = 50.5(x^2 - 3.00x + 2.00)$$

$$46.5x^2 - 151.5x + 101.0 = 0$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{-(-151.5) \pm \sqrt{(-151.5)^2 - 4(46.5)(101.0)}}{2(46.5)}$$

$$= \cancel{2.323} \text{ or } \boxed{0.935}$$

At 2000°C the equilibrium constant for the reaction

15.43

$$2NO(g) \rightleftharpoons N_2(g) + O_2(g) \qquad K_c = \frac{[N_2][O_2]}{[NO]^2} = 2.4\times10^3$$

is $K_c = 2.4\times10^3$. If the initial concentration of NO is 0.200 *M*, what are the equilibrium concentrations of NO, N_2, and O_2?

	$2NO \rightleftharpoons$	N_2	$+ O_2$
I	0.200M		
C	$-x$	$+0.5x$	$+0.5x$
F	0.200M $-x$	$0.5x$	$+0.5x$
	$\boxed{0.002M}$	$\boxed{0.0999M}$	

$$\sqrt{\frac{(0.5x)^2}{(0.200M-x)^2}} = \sqrt{2.4\times10^{+3}}$$

$$\frac{0.5x}{0.200M-x} = 2.4\times10^3$$

$$0.5x = (2.4\times10^3)(0.200M - x) \rightarrow x = 0.199$$

For the equilibrium

$$Br_2(g) + Cl_2(g) \rightleftharpoons 2BrCl(g) \qquad K_c = \frac{[BrCl]^2}{[Br_2][Cl_2]} = 7.0$$

at 400K, Kc = 7.0. If ~~3.0~~ 0.30 mol of Br_2 and 0.30 mol of Cl_2 are introduced into a 1.0 L container at 400K, what will be

15.44 the equilibrium concentrations of Br_2, Cl_2, and BrCl?

	Br_2	$+ Cl_2$	$\rightleftharpoons 2BrCl$
I	0.300M	0.30M	0
C	$-x$	$-x$	$+2x$
E	(0.300 M$-x$)	(0.30M $-x$)	$2x$
	$\boxed{0.129M}$	$\boxed{0.129M}$	$\boxed{0.342M}$

$$K_c = \frac{(2x)^2}{(0.300-x)^2} = 7.0$$

$$\frac{2x}{0.300-x} = 2.65$$

$$4.65x = 0.795$$

$$x = 0.171$$

Consider the reaction

$$CaSO_4(s) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq) \qquad K_{sp} = [Ca^{2+}][SO_4^{2-}]$$

15.47 At 25.0°C the equilibrium constant is $K_c = 2.4\times10^{-5}$ for this reaction. If excess calcium sulfate is mixed with water at 25.0°C to produce a saturated solution, what are the equilibrium concentrations of each ion? If the resulting solution has a volume of 3.0L, what is the minimum mass of calcium sulfate needed to achieve equilibrium?

a $K_{sp} = x^2 = 2.4\times10^{-5}$

$x = 0.0049M = [Ca^{2+}] = [SO_4^{2-}]$

b $0.0049\,M\,Ca^{2+} \times 3.0L = 0.0147\,mol\,Ca^{2+} \times \frac{1\,mol\,CaSO_4}{1\,mol\,Ca^{2+}} \times \frac{136\,g\,CaSO_4}{1\,mol\,CaSO_4} = \boxed{0.0294\,g\,CaSO_4}$

Multiple Concept Problem

At temperatures near 800°C, steam passed over hot coke (a form of carbon obtained from coal) reacts to form CO and H_2:

$$C(s) \quad + \quad H_2O(g) \quad \rightleftharpoons \quad CO(g) \quad + \quad H_2(g)$$

The mixture of gases that results is an important industrial fuel called *water gas.*

(a) At 800°C the equilibrium constant for the reaction is $K_p = 14.1$. What are the equilibrium partial pressures of H_2O, CO, and H_2 in the equilibrium mixture at this temperature if we start with solid carbon and 0.100 mol of H_2O in a 1.00 L vessel?

(b) What is the minimum amount of carbon required to achieve equilibrium under these conditions?

(c) What is the total pressure in the vessel at equilibrium?

(d) At 25°C the value of K_p for this reaction is 1.7×10^{-21}. Is the reaction endothermic or exothermic?

(e) To produce the maximum amount of CO and H_2 at equilibrium, should the pressure of the system be increased or decreased?

a.

$P_{H_2O} = \frac{nRT}{V} = \frac{(0.100)(R)(1073K)}{1.0L} = 8.8\,atm$

	C	H_2O	CO	H_2
I	—	8.81 atm	0	0
C	—	$-x$	$+x$	$+x$
E	—	8.81 atm $- x$	x	x
L		$\boxed{2.67\,atm}$	$\boxed{6.13}$	$\boxed{6.13}$

$K_p = \frac{[CO][H_2]}{[H_2O]} = 14.1$

K_c

$\frac{x^2}{8.81 - x} = 14.1$ $\qquad \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$x^2 = 124.2 - 14.1x$ $\qquad \frac{-14.1 \pm \sqrt{(14.1)^2 - 4(-124.2)}}{2} = 6.13$

$x^2 + 14.1x - 124.2 = 0$

b 6.13 atm H_2O consumed

$n = \frac{PV}{RT} = \frac{(6.13atm)(1.0L)}{(0.0821)(1073K)} = 0.0696\,mol\,H_2O \times \frac{1\,mol\,C}{1\,mol\,H_2O} \times \frac{12.0g\,C}{1\,mol\,C} = \boxed{0.835g\,C}$

c $\quad 2.67atm + 6.13atm + 6.13atm = 14.93atm$

d as T ↓ K_p ↓, therefore the Rxn is endothermic b/c lowering T favors the endothermic process. ~~Therefore~~, This lowers the K_p which means [Reactant] ↑ and [product] ↓. Thus K_p ↓

e Decreased. as P ↓ the Equilibrium shifts Right to favor the side of Rxn that has the greater amount of gaseous products.